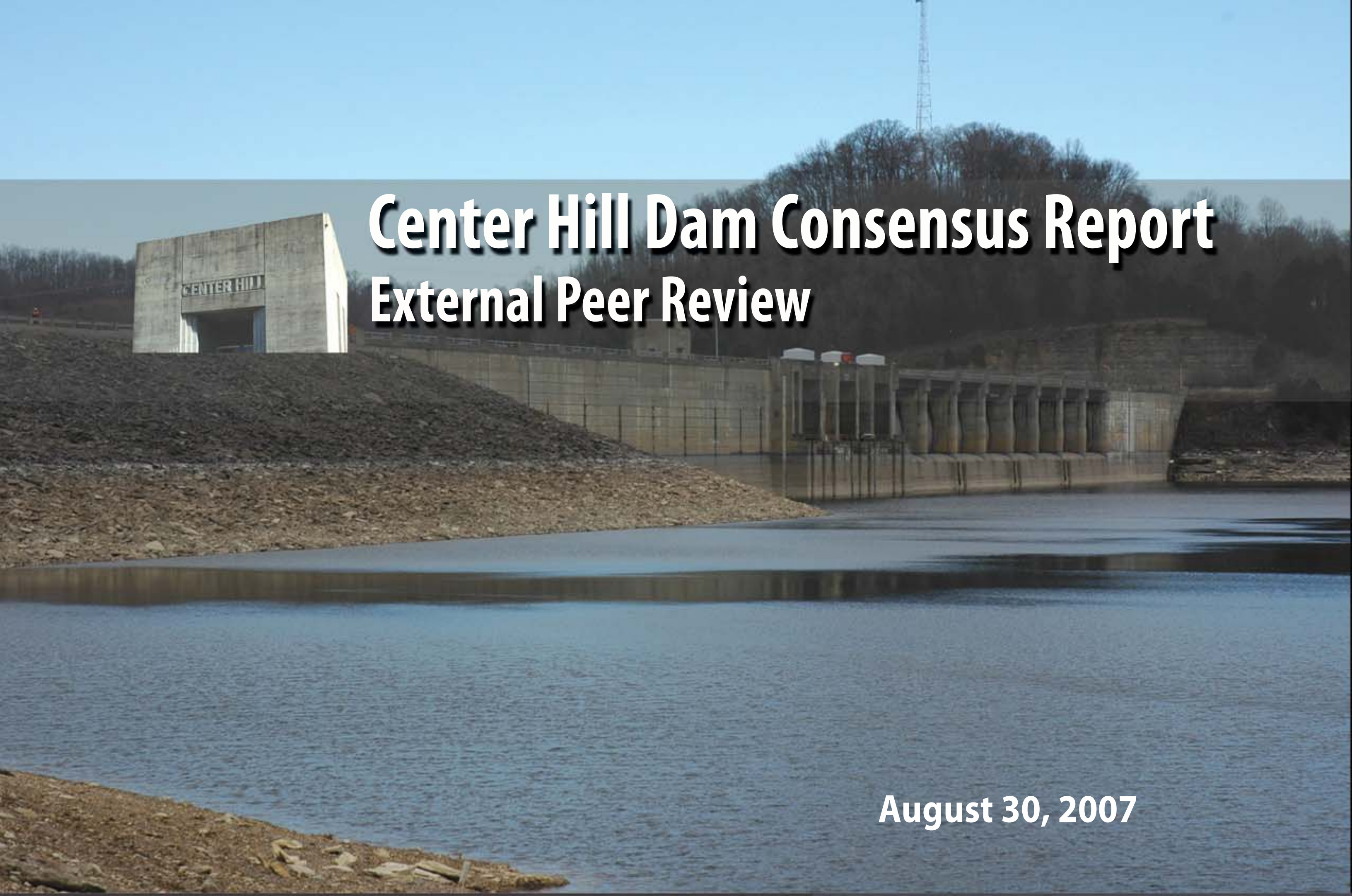
Center Hill Dam Consensus Report
External Peer Review



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Executive Summary

The U.S. Army Corps of Engineers (Corps) DSAC (Dam Safety Action Classification) External Peer Review Panel (Panel) has found that the Corps Class I designation (Urgent and Compelling) for Center Hill Dam under EC 1110-2-6064 "INTERIM RISK REDUCTION MEASURES FOR DAM SAFETY" dated May 31, 2007 is appropriate.

This finding is based on compelling evidence that a piping failure mode has initiated in or under the main embankment and through the right and left abutments as well as the saddle embankment dam section. The Panel finds this mode of failure in an advanced "continuation" stage of development, particularly in the abutments. Release of the reservoir through a solution cavity of the Karst abutment formations may not be as severe as a failure under an embankment where the dam could collapse quite suddenly and catastrophically due to sinkholes developing into large cavities under the dam. The less severe consequences of failure in the abutments are possible because the size of the cavities will likely restrict the release rates through the abutments to a smaller amount than through a breach in the dam. However, a failure through the known cavities in the abutment will likely cause loss of the reservoir and its benefits.

Although the Panel finds the piping in solution cavities a little less advanced in the foundation of the dams than in the abutments, our finding is that this failure mode is substantially advanced under the embankment sections (main dam and saddle dam). As a consequence, there is significant potential for a catastrophic failure of Center Hill Dam under normal operating conditions. It is not possible to make an estimate as to when such a failure would occur. It is essential therefore, that immediate action is taken to reduce risks to the public, and that investigations, grouting, and construction of other remedial measures are expedited.

The Panel's conclusions and recommendations are as follows:

1. **Immediate Action – Maintain a Lower Reservoir Level:** The Panel notes that the Corps has performed evaluations regarding the seepage concerns at Center Hill dam and continues to evaluate safety related issues regarding the dam's performance. As a result of these evaluations by the Nashville District and Headquarters, the Corps has implemented a modified pool operation plan that generally targets pool levels below elevation 630 in the winter and below elevation 648 in the summer. The Panel recommends immediate action to maintain the reservoir level more nearly in line with the Corps target levels for the winter by keeping the pool at or below elevation 620 to 630 all year until further information is available to evaluate the appropriate reservoir restrictions. This elevation was judged by the Panel as an appropriate target elevation based on our concerns about distress indicators that prompt a judgment for keeping the reservoir level as low as possible while still allowing operation of the facility for the most important functions. This judgment was further influenced by an

inspection of the project's performance at a pool elevation of 624 on February 8, 2007 and by our consideration of the need to reduce the pressure on the dam, foundation, and abutments as well as to reduce the volume of water in the reservoir. The smaller reservoir volume will reduce the risks downstream in the event of a failure.

The proper drawdown level cannot be determined at this time based on available instrumentation data, geological information, and a current understanding of potential consequences associated with lowered pool conditions. The Panel finds that current distress indicators with normal pool operation signify a risk of failure of the embankment dam or the saddle dam, and/or release of the reservoir through erosion features in one of the abutments or under the concrete dam. The Panel considers the recommended pool restrictions essential to reduce these risks, but recognizes that Corps may decide on other action based on judgments regarding consequences of using lower pool levels unknown to the Panel.

Coupled with operating at a lower pool level, the Panel recommends a review of the emergency action plan and performing an update if needed. Emergency response entities should be notified to be on an enhanced state of preparedness to follow the emergency action plan. Surveillance of the dam and the distress indicators should be maintained at a high level.

2. **Short-term Remedial Actions to be Started as Soon as Possible:** To reduce the risks of failure of the structure and to establish an appropriate restricted reservoir level, the Panel recommends the following short-term actions:

   a. **Begin Foundation and Abutment Grouting Program as Soon as Possible:** The planned grouting program for the main embankment dam, saddle dam, left abutment, and right abutment rim should be completed as soon as possible. The grouting should be accomplished using the most current methods to ensure the grout curtain is effective and that important information is collected for evaluating the reservoir restriction level and for design of the proposed cutoff wall or other remediation measures.

   b. **Update the Flood Routing and Consequences Evaluation:** An update of the flood routing and consequence evaluation should be completed as soon as possible to aid in the evaluation of pool restrictions.

   c. **Improve the Existing Instrumentation, Monitoring and Evaluation Program:** It is noted that additional piezometers are currently being installed. The Panel recommends a comprehensive peer review of the current and proposed instrumentation program be completed as soon as possible so that the current instrumentation system can be modified as needed. The purpose of the instrumentation and evaluation is to determine the condition of the main and saddle dams prior to, during, and following completion of an expedited grouting program.

The Panel recommends installing additional settlement monuments on the crest of the dam to make the spacing between monuments a maximum of 25 feet. Surveys on these closely-spaced monuments will provide better information relating to settlements that may be associated with loss of support under the dam due to erosion of soil from solution cavities.

d. **Perform a Formal Risk Analysis:** A formal risk analysis should be performed considering alternative reservoir restriction levels and downstream consequences to assist with project decision making and evaluation of reservoir drawdown and operations restrictions. The Panel notes that a contract has been awarded to perform a risk analysis on Center Hill Dam.

e. **Review Reservoir Restrictions:** Once completed, the results of the supplemental investigation, instrumentation monitoring, and grouting programs should be reviewed to determine whether the reservoir restrictions are appropriate and to make modifications if needed.

The Panel recognizes that the District has already started work on one or more of these recommendations. Each of these recommendations is discussed further in the main sections of the report along with long-term risk reduction measures.

3. **Long-term Risk Reduction Measures Evaluation and Design:** The Panel recommends the following process for determining and implementing the appropriate long-term remedial measures:

   a. **Revisit the alternatives analysis:** The Panel recommends that the previous alternatives analysis be revisited and that alternatives be developed and evaluated that would weigh the options that allow a cutoff wall to be installed from the foundation level. These options could be a new RCC dam or partial/full removal/replacement of the existing embankment dams with appropriate foundation preparation and treatment. The cutoff wall installed from the foundation level will have a much longer life than one installed from the embankment crest and a concrete dam will be much more resistant to erosion than the present embankments. The new alternatives analysis should evaluate and compare short and long-term risk reduction measures so that a “risk informed” decision can be made considering the best value over the long-term versus one based on today’s least cost and least negative consequences.

   b. Proceed with the design and construction of the alternative selected based on best value.

Further details of these conclusions and recommendations are included in the main sections of the report.

1.0 Introduction

1.1 Project Description

Center Hill Dam is owned by the U.S. Army Corps of Engineers and is operated by the Nashville District of the Corps of Engineers. It is a combination concrete gravity and earth fill structure located at mile 26.6 on the Caney Fork River in DeKalb County, Tennessee. The Caney Fork River is a major tributary to the Cumberland River. The Center Hill Dam has been in service since 1951. The overall length of the dam is 2,160 feet and the maximum height is 250 feet. The concrete dam section is 1,382 feet long, ties into the right abutment and extends across the old river channel. The rolled earth embankment is 778 feet long and ties into the left abutment. There is a saddle dam located in the right rim of the reservoir with a total length of 770 feet and a maximum height of 125 feet. The main dam concrete section contains a gate control spillway section, a powerhouse section, and non-overflow sections on both ends. State Highway 96 extends along the top of the dam.

The control section contains a spillway with eight 50-foot wide, by 37-foot high tainter gates and six 4-foot by 6-foot low level sluices at an invert elevation of 496.0 feet. The top of the dam is at elevation 696.0; the crest of the spillway is at elevation 648.0 where the storage capacity of the reservoir is 1, 330,000 acre-feet; and the top of the tainter gates is at elevation 685.0 where the storage capacity is 2,092,000 acre-feet (top of flood pool). Power can be generated when the pool elevation is at or above elevation 618 (some vortex development and air suction may be a problem at elevation 618). The powerhouse contains three turbines rated at 45,000 kw each for a total generating capacity of 135 megawatts.

The concrete section of the main dam was keyed into bedrock and grouting pipes were installed in the galleries of the dam to provide for drilling and grouting after the concrete had been placed. Excavation into bedrock was sufficient to found the concrete section on competent rock that was smooth and free of large open cracks. The grout curtain generally extended 30 or more feet in depth below the base of the concrete and into the right abutment using angle holes. Working from the right abutment (Monolith 1) toward the left, grout takes were modest up to Monolith 16, but become much larger between Monoliths 16 and 19.

According to the Corps Major Rehabilitation Evaluation Report, Seepage Control, Final Report dated July 2006 (MRE Report), a thin, impervious bentonitic shale layer exists about 35 feet below the founding elevation of the concrete dam Monoliths (designated the T3 bentonite marker). Investigations found the bentonitic shale traps water beneath it thereby creating uplift pressures under the layer. Relief wells have been installed to relieve these pressures and provide drainage.

Many open Karst features were found beneath the T3 bentonite layer and grouting from the concrete dam galleries was extended up to 100 feet in depth. Between Monoliths 14 and 29, all holes consumed large quantities of grout without any pressure. It was reported by the Corps that some grout holes seemed to exert suction on the hose line for injecting grout. Forty primary holes consumed 23,234 cubic feet of cement and 4,204 cubic feet of limestone dust. All grout holes were grouted to refusal at 75 pounds of pressure.

The main dam embankment lies primarily on alluvial and residual soils, with the exception of a narrow cutoff trench just downstream of the dam axis. Alluvial deposits are composed of 15 to 20 feet of finely graded sands, silts and clays, except near the left abutment where they consist of 20 to 30 feet of residual fat, silty clays with weathered rock fragments. The state-of-the-art practice used in the 1940s of leaving the soil deposits in place did not allow for adequate inspection or treatment of the rock along the entire embankment footprint during construction.

The cutoff trench under the embankment section was designed with 1H:1V side slopes, and was excavated through the Catheys and Cannon bedrock formations with near vertical sides. Construction was delayed during World War II which caused the cutoff trench to be excavated in two segments. An off-set in the trench alignment of 12 feet was made to avoid some jointed rock. The cutoff trench ranges in depth up to 30 feet primarily in the Catheys and Cannon Formations that consist of limestone riddled with fractures and cavities ranging in size from a fraction of an inch up to more than 50 feet. The larger vertical cavities encountered in the trench were backfilled with concrete, and the remainder was filled with clay. Placement and compaction was often performed by hand against the rough, vertical sides of the trench. Obtaining good compaction at the sides of the trench was not considered important at the time of construction; therefore, the sides of the cutoff trench likely allow considerable seepage to pass.

A single row grout curtain was installed in the bottom of the cutoff trench under the embankment section to a depth of 50 feet. Grout holes were drilled vertically on 5-foot centers in a single row according to the state-of-the-art practice of the time. Using a single row and only vertical holes would not meet current standards. The grouting encountered large cavities, such as the one at Station 16+80L that took 4,119 cubic feet of cement indicating large open cavities before the reservoir existed. The left half of the embankment foundation consumed 83 percent of the total grout (42,770 cubic feet of cement or grout solids). The large grout takes prompted the Corps to add four 36-inch diameter Calyx holes to investigate the bentonite layer under the powerhouse, define open bedding planes, and investigate the large grout takes under the embankment section. After the Calyx holes were drilled, designers increased the depth of grout holes between Stations 20+45L to 23+20L from 75 feet to 100 feet. No other treatment of the foundation was performed during construction.

Seepage through the left abutment rim became evident during the initial filling of the reservoir in 1949. The Picnic Spring increased in flow from 1 cfs before reservoir filling to over 38 cfs when the reservoir reached elevation 629 feet. In 1949, the reservoir was lowered to elevation 583 and an extensive grouting program was performed along the left rim of the reservoir using a single line grout curtain that extended 3,500 feet long. A noteworthy detail of the grouting program is that grouting was suspended for approximately 400 feet through a section of the ridge that is capped by shale rock. The designers at the time believed the shale cap had protected the limestone rock from solution activity and grouting was not needed in this section. Later investigations have shown that this "gap" in the grout curtain of the left abutment rim to be a major defect in the defense against seepage and piping in the Karst features.

The 1949 grouting along the left abutment rim of the reservoir did reduce the seepage at the Picnic Spring to about 1 cfs, but it gradually increased over the years and in the late 1980's, sinkholes begin to develop both upstream and downstream of the grout curtain. In the spring of 1991, during a record high pool, 5,000 cubic yards of chert and clay discharged from the Picnic Spring and new sinkholes appeared on the downstream side of the abutment. In 1993, a second 2,127 foot-long, single-line grout curtain was installed along the same alignment as the original curtain. The 1993 curtain was designed with the intent to close the 400-foot gap in the original curtain. The gap was reduced, but a section approximately 150 feet long could not be grouted because the cavities were too large. One cavity was encountered 200 feet beneath the surface that measured approximately 80 feet high and 15 feet wide. The 150 foot-long gap still exists in the grout curtain on the left rim of the reservoir.

Seepage problems under the embankment dam started to become evident in 1969 with the development of a small sinkhole at the toe of the wraparound section downstream of the powerhouse, whereupon piezometers and other instrumentation were then installed. In 1974, wet areas were noted downstream of the embankment section of the main dam. Two small areas of muddy flow were discovered along the left bank downstream of the powerhouse retaining wall in 1982. Large seepage flows have also occurred on the downstream side of both the right and left abutments. Additional grouting has been performed in the dam and abutments because large springs had developed and sinkholes formed. These events are further explained in Section 3 of this report.

1.2 References and Sources of Factual Data

A listing of the references that were used as sources of information is provided in Attachment A. The scope of the Panel's work was to review summaries of the large amount of information developed for the Center Hill Dam site. These summaries and interpretations have been prepared mainly by Corps personnel. The Panel has found the information well prepared and very helpful. We have relied on the accuracy of these summaries and technical interpretations and in particular the analysis of the distress indicators that have been identified and documented.

The Panel has carefully considered the verbal and written opinions of all investigators who have been part of the ongoing investigations or who have previously reviewed and evaluated the condition of the dam.

2.0 Site Visit Observations and Recommendations

2.1 General

Four members of the Peer Review Panel (all except Dr. Poulos and Dr. Bruce) visited the site with Messrs. Jodi Stanton, Timothy McCleskey, and Rob Brimm of the Nashville District on February 8 and 9, 2007 for the purpose of supporting the development of opinions and recommendations, and preparation of this consensus report. Dr. Bruce has worked on and visited Center Hill Dam in the past. A summary of the key findings related to our site visit is provided below. Illustrative photographs taken during the site visit and referenced in the text that follows are presented in Attachment B. Conclusions and recommendations that are based on the site visit are included in Section 7 – Conclusions and Recommendations.

2.2 Large Springs or Concentrated Seepage Flows

The Panel observed large springs or concentrated flows from cavities in the bedrock in both abutments of the dam. Two caves are located downstream of the right abutment. One is the outlet of the "Lower Leak" also known as the Corps of Engineers Cave, the other is approximately 500 feet downstream of the lower leak and is known as the Boat Ramp Cave. The entrance of both caves is about elevation 503 feet. Both caves have formed within the Lower Cannon Formation with the floor of each cave located at the contact with the horizontally bedded Hermitage Formation.

In 2001, a contract survey team mapped the two right abutment cave systems. The Corps of Engineers Cave was mapped for a distance of 136.9 feet from the entrance, but mapping stopped short of the end because water velocity and limited airspace made further access hazardous. The Boat Ramp Cave was dry at the time of the survey and was surveyed for a length of 137.8 feet.

The reservoir level at the time of this site visit was at elevation 624 feet. The reservoir is normally higher than it was during the site visit, therefore; the springs were flowing at a lower rate than normal. No spring flow measurements were made during the site visit, but the lower leak was flowing strongly (perhaps up to 5 or 10 cfs) and no flow was observed from the Boat Ramp Cave (see Photographs No. 1 & 2). The Panel members could not get close enough to the Corps of Engineers Cave outlet during the site visit to observe whether the flowing water was turbid.

We also observed the two springs on the downstream side of the lower left abutment (the Picnic Spring and the Quarry Springs). The Picnic Spring is a concentrated flow from a cave-like feature at the base of the abutment. The Quarry Springs consists of a series of flows from the vertical excavation face of the rock quarry along the left abutment downstream from the dam. Flow measurements were not made during the site visit. By observation, the Picnic Spring flow was estimated to be about 3 to 5 cfs and the Quarry Springs flow was estimated to be approximately 2 to 3 cfs. The flow from the Picnic Spring was observed to be slightly cloudy (appeared to have some clay particles in it) (see Photographs No. 3 & 4).

2.3 Large Active Sinkholes in the Left Abutment

The Panel observed large sinkholes at the surface on the downstream side of the left abutment, apparently along the alignment of cavity features leading from the left rim of the reservoir to the Picnic Spring and/or Quarry Springs area (see photograph No. 5). We also observed a sinkhole in the left bank of the reservoir at the existing lake water surface (elevation 624) (see Photograph No. 6).

The Panel believes that piping of the infilling material in solution features of both abutments was initiated many years ago (likely earlier than 1969 or 1970). The grouting operations in the 1970's and in 1993 served as a temporary deterrent to piping through those areas where the grout curtain was installed; however, piping has resumed since grouting was completed and has continued (perhaps accelerated) in the gap left in the grout curtain on the left abutment. The piping is evidenced by the increasing spring flow and the formation of sinkholes along an alignment from the springs to the reservoir as shown on Figure 1. Figure 1 is the same as Figure 3-27 in the Center Hill Dam MRE Report, which shows the left rim seepage and sinkhole features, geologic information, and the approximate alignment of the grout line with the gap (area not grouted).

The Panel believes that large open flow channels exist in both abutments, progressing from the downstream toward the reservoir. A large breakthrough of one or more flow channels into the reservoir will likely occur in the near future that will release large flows from the reservoir to the downstream channel. Since these flow channels will be restricted to the size of the solution features in the rock, the downstream flooding caused by such a breach would likely be less than the Standard Project Flood. Based upon previous downstream flood routings of this occurrence in either abutment, peak flows would be approximately one-third to one-quarter of the peak flow caused by a collapse of the main embankment or saddle dam. Such a failure would, however, empty the pool causing the loss of the reservoir and its benefits.

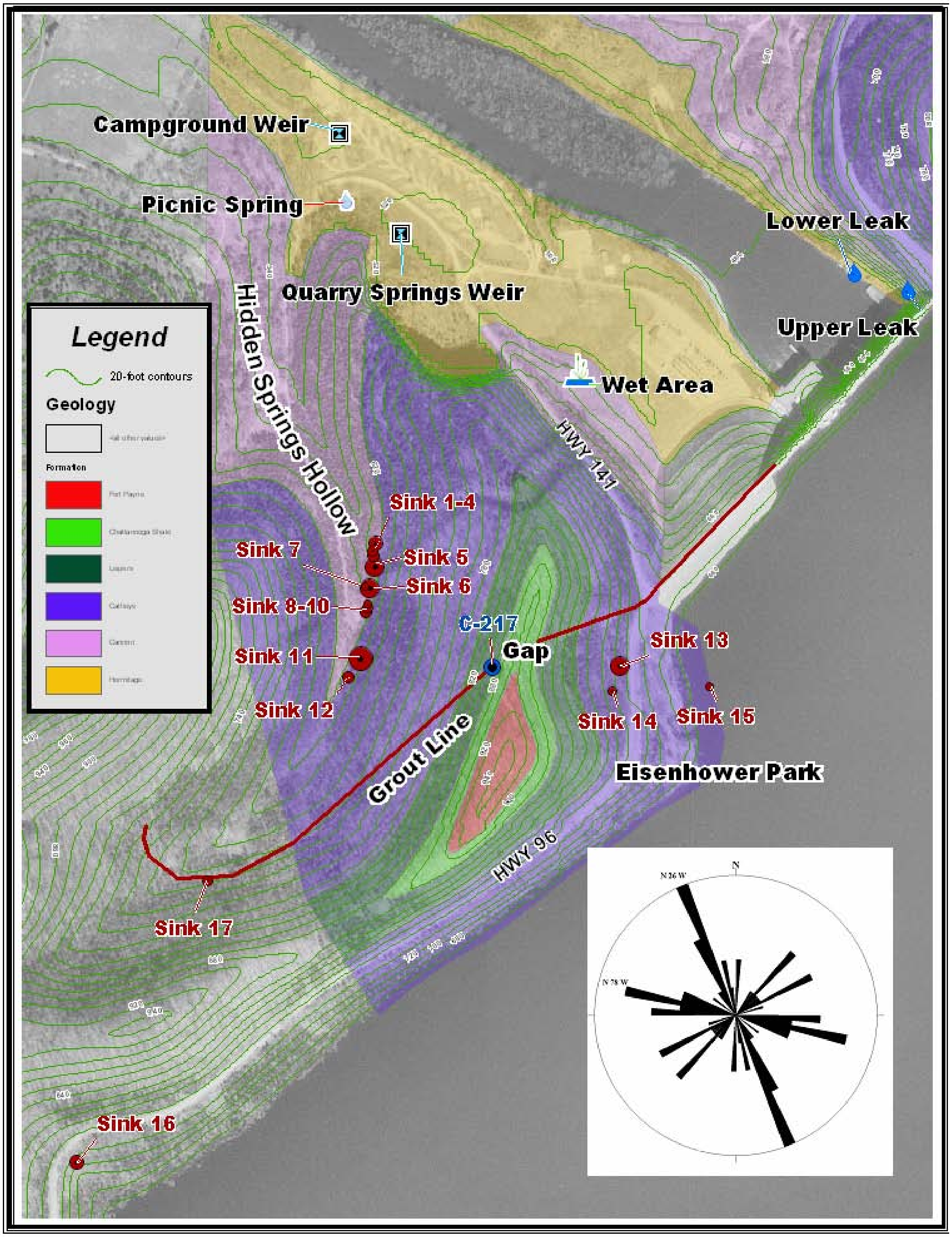


Figure 1 Left Rim seepage and sinkhole features and geologic information.
Joint rosette in bottom right.

2.4 Wet Areas Along the Base of the Left Abutment

The Panel observed wet areas along the base of the left abutment just downstream from the embankment section. The ground was moist to slightly wet with a few spots of standing water, and very little running water. Based on the visual characteristics of the vegetation, it is apparent that this area is extremely wet during higher reservoir levels. Corps personnel reported on excavations made in these wet areas. Water flowed up from the bedrock surface that was exposed in the bottom of the excavations. The excavations were made when the reservoir levels were higher than during the site visit.

It was reported by the Corps that these wet areas have increased in volume and area over the years. There has been some sinkhole development near the downstream toe of the dam, but the cause is unknown and none have occurred in recent years. In addition, there have been changes in piezometer levels measured in the foundation of the embankment section of the dam upstream from the wet areas (some rising and some dropping). Temperature readings taken in the piezometers showed colder water in two zones under the embankment section upstream from the wet areas indicating seepage directly from the reservoir in two seepage channels (one between Stations 17+00L and 19+00L and the other near the concrete dam and embankment interface). The Panel considers these observations to indicate that piping is also active in the foundation area under the embankment section of the dam and particularly near the concrete and embankment dam interface as evidenced by the changing piezometer levels and cold temperatures. The downstream wet areas have nearly dried up with the reservoir level below elevation 625, indicating perhaps pool restrictions have improved the situation, but it is not possible to tell how much seepage may be bypassing the downstream area in the Karst features of the foundation.

2.5 Concrete Dam Galleries

The Panel members inspected the galleries in the concrete section of the dam. It was noted that very little movement has occurred between Monoliths and that very little leakage is occurring from most of the Monolith joints. The Corps reported that a horizontal lift joint at elevation 614 was leaking in the early 1970’s. In 1974, several post-tensioned anchors were installed through the spillway Monoliths which reduced this leakage. It was also noted during our site visit that discharge from shallow foundation drains into the gallery is minimal. The District has reported that the shallow foundation drains in the concrete section are monitored and maintained on a regular basis. Historically, these drains have experienced moderate to heavy mineral deposits. The drain holes are flushed using high water pressure and reamed out with a roller rock bit every five years. A limited number of the deeper holes that relieve the uplift pressures below the T-3 bentonite layer have been cleaned out on a roughly 5-year schedule using high pressure water jets. During these activities care has been exercised to avoid water cutting of the softer bentonite layer.

2.6 Settlement of the Embankment Dam

The Panel looked for evidence of settlement or distress of the main embankment dam's crest and downstream slope. Depressions were observed along the crest of the existing embankment dam adjacent to the left end of the concrete section. Our observations suggest that active settlement of the embankment dam is occurring in the area between the end of the concrete dam section and the first settlement monument which is 100 feet to the left of the end of the concrete dam (see Photograph No. 7).

Settlement monuments have been placed on the downstream edge of the crest of the embankment section of the dam and monitoring started in the early 1970's. The settlement reported in the MRE Report is for the period from 1970 to 2005. The monuments have a spacing of 100 feet and show settlement ranging from about 0.10 feet to 0.32 feet in the 35-year period. The maximum settlement of 0.32 feet is at Station 17+00. This location coincides with the piezometer locations where cold temperatures were recorded. The Panel recommends that the monitoring points should be more closely spaced, particularly near the end of the concrete section of the dam.

2.7 Saddle Dam and Fuse Plug in Right Abutment

The Panel inspected the saddle dam and fuse plug in the right abutment rim. Visually, the saddle dam and fuse plug spillway show no signs of distress. However, visual observation is limited due to riprap on the upstream slope and concrete below the fuse plug fill on the downstream slope. The Panel's concern for the saddle dam is based on the fact that 25 percent of the grout holes installed in the curtain in 1942 were not grouted to refusal at the required pressure. Some of these grout holes had large grout takes indicating large cavities or cracks in the foundation. A number of springs have appeared downstream that flow strongly when the reservoir is above elevation 648. Instrumentation is limited to only 6 piezometers and they show very little head loss across the 60-year-old grout curtain. The Panel recommends a system of piezometers and settlement monuments be installed, monitored, and evaluated for the saddle dam.

2.8 Investigation for Grouting Work Underway

The Panel noted that some investigation work was underway during its site visit. A drilling program had been initiated starting from the crest of the main embankment dam to determine conditions for the short-term remediation work of installing a grout curtain in the foundation of the embankment section. This investigation work also includes installing piezometers in and under the embankment section. Details of this program and the results of the investigations and instrumentation monitoring have not been reviewed by the Panel.

3.0 History of Seepage and Other Issues

3.1 General

Uncontrolled seepage through the rock foundation of the embankment, saddle, and gravity dam sections as well as the abutments has threatened the seepage stability of Center Hill dam since at least the late 1960's. The original design and construction techniques used at Center Hill Dam followed the standard of practice for dams built on Karst foundations in the 1930s and 1940s. However, several aspects of the foundation design have subsequently contributed to the development of serious seepage and piping problems as has been the case for a number of dams on Karst foundations that were designed during the same period.

According to the Corps 2006 MRE Report, large cavities and joints exist in the bedrock of the foundation and abutments of the dam as a result of long-term solution activity in the limestone rock. The MRE Report indicates the large cavities are mainly concentrated at the contacts between each of the Catheys, Cannon, Hermitage, and Carters formations. These formations constitute the major geologic features at the site (sequentially from top to bottom). Before the dam was constructed, the solution cavities were generally filled with soil. Under the pressure of the reservoir head, which typically ranges between 125 and 150 feet, piping and internal erosion of the cavity filling material has occurred.

As water erodes material from the Karst features, the overall size of the opening conveying the water continues to grow to the size of the Karst feature. As erosion progresses, there is an increasing volume of water flow, a higher water velocity and higher erosive potential. Ultimately, this internal erosion can reach the contact between the bedrock and the overlying foundation soil and/or embankment and undercut the overlying material, resulting in embankment settlement and/or the formation of sinkholes. Sinkholes can form in the dam if the internal erosion occurs under the dam or in the abutment overburden material above where these cavities are created.

3.2 Left Abutment

As reported previously, excessive seepage through the left abutment became evident during the initial filling of the reservoir in 1949 when the Picnic Spring increased from 1 cfs to 38 cfs as the reservoir was raised to elevation 629 feet. The large seepage prompted grouting on the left abutment rim of the reservoir in 1949 after which the seepage was reduced to a small amount. A 400-foot wide gap was left in this grout curtain. Seepage gradually increased in the left abutment and sinkholes developed both upstream and downstream of the grout curtain over the years with some very large soil discharges in downstream springs. As a result of these distress indicators, additional grouting was performed in 1993 along the same alignment as in 1949 and an attempt made to close the gap in the grout curtain. The last 150 feet of the gap could not be closed because of excessively large cavities deep in the abutment rock. The 150-foot wide gap in the grout curtain still exists today. Left abutment seepage is still very large and sinkholes continue to develop.

Since the 1993 left abutment grouting was completed, the seepage has continued to increase downstream of the left abutment with large spring flows that sometimes run muddy. In addition, sinkholes have been found along the upstream side, the top surface, and the downstream side of the left abutment.

3.3 Right Abutment

A grout curtain was designed for the right abutment rim to be installed during the original construction, but for undocumented reasons, was never installed. Shortly after the initial reservoir filling in 1949, a small leak of less than 1 cfs appeared in the right abutment next to the dam at elevation 580. By 1959, this “Upper Leak” had increased to over 5 cfs. A grouting program using 35,000 pounds of hot bitumen successfully intercepted and sealed the leak. Within a year, seepage had appeared again in the upper leak and continued to increase over the years.

In 1965, another leak flowing at about 1 cfs appeared on the right abutment 200 feet downstream from the main concrete dam. This “Lower Leak” is at elevation 504. Flow in the Lower Leak was measured at 4 cfs in 1968 and 6 cfs in 1971. In 1976, flow from the Lower Leak became muddy, discoloring much of the tailwater. Muddy flow continued to increase until the flow reached 19.2 cfs in 1996. The weir box was damaged by high flows in 2003 and no measurements have been possible since.

At the same time that grouting was performed in the left abutment in 1993, grouting was also extended to the right abutment. A fan-shaped triple line grout curtain consisting of two cement grout lines and one chemical grout line was installed in the right rim of the reservoir. The grouting failed to intercept the Lower Leak, but was successful in reducing the Upper Leak to 1 cfs. However, in 1996, a new leak emerged about 50 feet downstream and at the same elevation as the Upper Leak. Since 1996, this new leak has increased to about 2 cfs.

3.4 Main Embankment Dam

For the first 18 years after construction, no problems were detected under the embankment section of Center Hill Dam. In 1969 a small sinkhole developed downstream of the embankment adjacent to the powerhouse tailrace. In 1974 inspectors noted wet areas downstream of the embankment. This observation prompted studies that included temperature profiling in piezometers located near the top of bedrock and exploratory drilling in the foundation and abutments. Two zones of colder temperatures were found in the piezometers indicating that water in the piezometers had a direct connection to the reservoir. During exploratory drilling, many solution cavities were found crossing under the cutoff trench.

In June 1982 a muddy flow was observed approximately 150 feet downstream from the end of the tailrace retaining wall emerging from the riprap protection along the left bank. The flow was estimated to be about 10 gallons per minute and was carrying fines and brown, fine, uniform sand. An additional breakout of muddy flow occurred within 70 feet of the first. Some filter material was placed over the springs at that time. No further muddy flows have occurred in this area since.

In response to these adverse findings, a grouting program was performed from 1982 to 1984 along the axis of the dam and across the left abutment that involved large grout takes in some holes and discovery of many voids under the dam. Drilling for the grouting was on 2.5 foot centers. Voids were found at the contact between the embankment and the foundation rock. Grout take was particularly heavy in or toward the left abutment. Over 7,460 cubic feet of solids were injected in grout holes between Stations 24+00L and 24+30L.

Surface monuments were installed in 1968 on the main embankment section of the dam along with piezometers installed in the foundation under the embankment section. According to the record provided to the Panel, the maximum settlement from 1970 to 2006 was 0.32 feet at Station 17+00L. This coincides with the location of dropping piezometer levels independent of the reservoir level and with the zone of cool temperature readings in the piezometers located in the upper levels of the foundation bedrock.

Currently, all piezometers located upstream of the axis of the embankment section measure between 85 and 95 percent of the headwater. Piezometers immediately downstream of the cutoff measure 85 percent of the effective headwater, indicating the cutoff and grout curtain under the embankment section is nearly ineffective.

3.5 Main Concrete Section

Uplift pressures caused problems for the deepest portion of the foundation excavation for the powerhouse during its construction and in early fillings of the reservoir. Heaving of the rock under the powerhouse was determined to be due to pressures under the T3 bentonite marker bed that slopes downstream from the reservoir, trapping water pressure under the low permeable layer. To reduce uplift pressures, 129 relief wells were installed in 1951 to a depth of 90 feet under the concrete section of the dam. These relief wells extend below the T3 bentonite marker bed and are connected to a header pipe in the gallery of the concrete dam section. The header is routed up the stairwell of the dam with the outlet of the header at elevation 495.0. This elevation corresponds to the assumed uplift pressure used for the original stability design of the concrete structure. There is no flow from the header system except when the pressure in the header system gets above elevation 495, usually during flood conditions.

There are an additional 44 relief wells installed under the powerhouse. A manifold system in the gallery of the concrete dam section collects flow from the powerhouse relief wells. These flows are pumped to a discharge location downstream of the dam in the tailrace section. Flow from the manifold system is reported to be substantial, but is not measured. An additional 24 relief wells were installed in the tailrace rock downstream from the powerhouse in about 1957. Eight of these wells flow strong enough to cause water boils at the water surface with 8 to 10 feet of submergence over where the relief wells are discharging vertically.

The stability of the concrete section was analyzed in 1989 by the Nashville District for a flood level higher than the original design. In the Corps analysis, internal stability in the upper portion of six concrete Monoliths was found to be marginally inadequate according to current Corps criteria for sliding and overturning during passage of the design flood (pool levels above elevation 691). Based on the analysis, the Corps recommended the use of anchors through these six Monoliths of the dam to meet stability criteria. District personnel have reported to the Panel that vertical post-tensioned anchors were installed in 1993 and 1994 through Monoliths 6, 7, 15, 16, 17, and 18 of the dam from the top of the dam (elevation 696) down to elevation 632.31 in the concrete at each Monolith as recommended to meet stability. The Panel has not seen or reviewed any information on the installation of the anchors.

3.6 Saddle Dam

The saddle dam in the right rim of the reservoir was constructed with a shallow cutoff trench extending 2 to 10 feet into rock. The 125-foot-high saddle dam is founded on the Cannon and Catheys Formations. A single-line grout curtain was used for additional seepage cutoff below the cutoff trench. Shallow and deep treatment was used with grout hole spacing at 10 feet for the shallow holes and 25 feet for the deep holes. The shallow holes were 15 feet deep and the deep holes were 75 feet deep. Large joints were encountered and they had problems with grout loss from venting (loss of grout to the surface through rock joints). Approximately 25 percent of the holes could not be grouted to refusal at the required pressure. The incomplete grouting has compromised the effectiveness of the grout curtain and constitutes a major cause for concern regarding the adequacy of the saddle dam foundation.

The saddle dam was completed in 1942 and no remedial grouting has been accomplished in this dam since completion. Several springs have developed on the downstream side over the years and piezometers installed in 1968 show only about a 10 percent loss of head across the cutoff and grout curtain. The increased spring development and lack of head loss across the cutoff indicates open channels for seepage under the dam.

3.7 Summary of Seepage Issues

Uncontrolled seepage through the rock foundation and abutments is causing the progressive piping of material infilling large and small solution cavities in the Karstic limestone. Progressive piping is evidenced by the increasing seepage and periodic muddy flows in the downstream springs and flows from cave features as well as increasing wet areas and large flows from relief wells downstream of the dam. Large sinkholes are developing along the left abutment as the piping removes material in cavities under the surface of the abutment creating a loss of support for the overlying soil and rock profile. The continued progression of this piping will eventually cause loss of the reservoir through large cavities in the abutments, under the concrete section of the dam, or it will cause collapse of the embankment section as sinkholes develop in the upstream slope resulting in rapid erosion, breach of the dam, and loss of the reservoir.

4.0 Continuum of Failure Timeline

4.1 Graphic Depiction of the Continuum of Failure Timeline

The Panel has developed a graphical depiction of a seepage failure mode continuum and has presented this depiction in a separate memorandum (DSAC Peer Review Panel, December 14, 2006). The failure continuum summarizes four stages of failure development and three corresponding intervention strategy categories as seepage failures progress along the continuum. The continuum is illustrated on Figure 2.

4.2 Safety in Context of Failure Continuum

The Panel's estimate of the current condition related to the failure mode continuum for seepage under the embankment section of the Center Hill Dam is shown on the diagram on Figure 3. Figure 3 indicates that a seepage related failure mode has initiated and is in a relatively advanced continuation stage under the main embankment dam. The Panel has made a separate estimate of the current conditions related to the failure mode continuum for seepage failure in the abutments of the dam. The condition for the left abutment is shown on the diagram on Figure 3 and the condition for the right abutment is shown on the diagram on Figure 4. Figures 3 and 4 indicate that a seepage related failure mode has initiated in the abutments, has passed through the continuation phase, and is possibly in the beginnings of the progression phase, but likely more advanced in the left abutment,. If the progression phase has started in the abutments, all that remains is for the erosion to remove additional material from the cavities causing a large break-through into the reservoir in order for failure to occur. The confidence intervals of the Panel's current assessments are also shown on Figures 3 and 4. The Panel believes that the conditions at the site indicate failure of Center Hill Dam could occur under normal pool operation.

In the Panel's opinion, the most advanced piping development and consequently the most likely failure mode is a major breakthrough of the reservoir into a solution feature in one of the abutments. Occurrence of this failure mode would likely drain a significant portion, or perhaps the entire reservoir. However, because of the limiting dimensions of Karst features in the abutments, the downstream consequences of this failure mode development may be less than would occur if the failure was from collapse of the dam. However, the Panel considers there is also a relatively high possibility that failure could occur from continued piping of cavity infilling under the embankment section of the dam sufficient to result in the formation of sinkholes in the upstream slope of the dam similar to the sinkhole development at Clearwater Dam. The reservoir could be released into sinkholes on the upstream slope, causing severe and rapid erosion and collapse of the earth embankment section. This more catastrophic failure is also possible at the saddle dam. Such failures would result in a rapid release of the reservoir and severe flooding downstream resulting in a potential for significant loss of life.

Figure 2

Seepage Failure Mode Continuum

Long-term intervention may include:

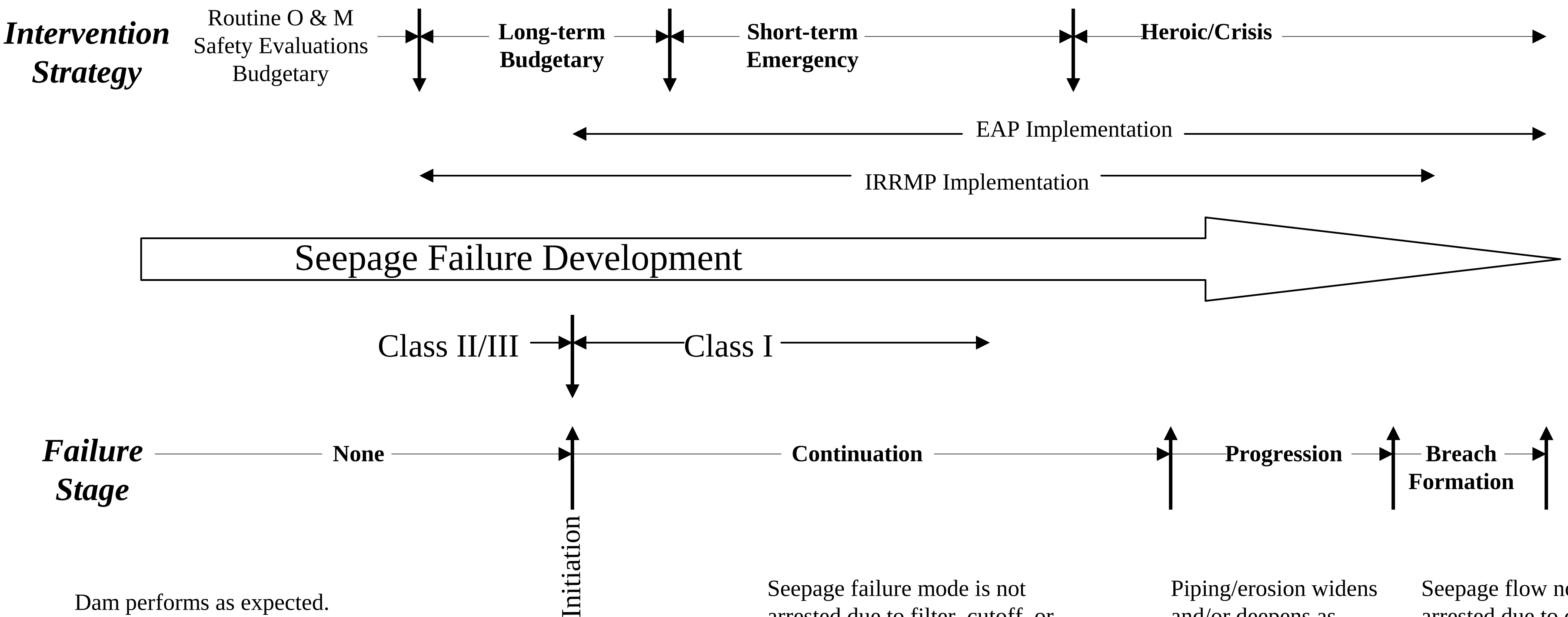
- Filters/drains
- Positive cutoffs
- Grouting
- Filter/drainage berms
- Relief wells

Short-term intervention may include:

- Modified operations
- Reservoir drawdown
- Reservoir restrictions
- Grouting
- Filter/drains/berms
- Relief wells

Heroic/Crisis intervention may include:

- Emergency drawdown
- Evacuation of downstream residents
- Filters
- Downstream gradient reduction
- Crack or pipe filling



Dam performs as expected. Routine safety inspections show no problems. Safety evaluations may suggest potential for long-term seepage concern.

Seepage failure mode initiates due to loading event that causes development of concentrated leak or backward erosion. Initiation may occur in the embankment, in the foundation, or at the interface between the embankment and foundation.

Seepage failure mode is not arrested due to filter, cutoff, or other intervention activity. The piping or erosion continues toward the source of water at accelerating rate due to increasing gradients and flow quantity.

Piping/erosion widens and/or deepens as flows increase due to roof formation and no other restraint to growth. Amount of flow continues to increases causing piping/erosion feature to grow rapidly.

Seepage flow not arrested due to collapse and erosion continues until dam crest is breached due to sinkholes, crest settlement, instability of slopes, or unravelling of the downstream slope

Prepared by DSAC Peer Review Panel
12-06

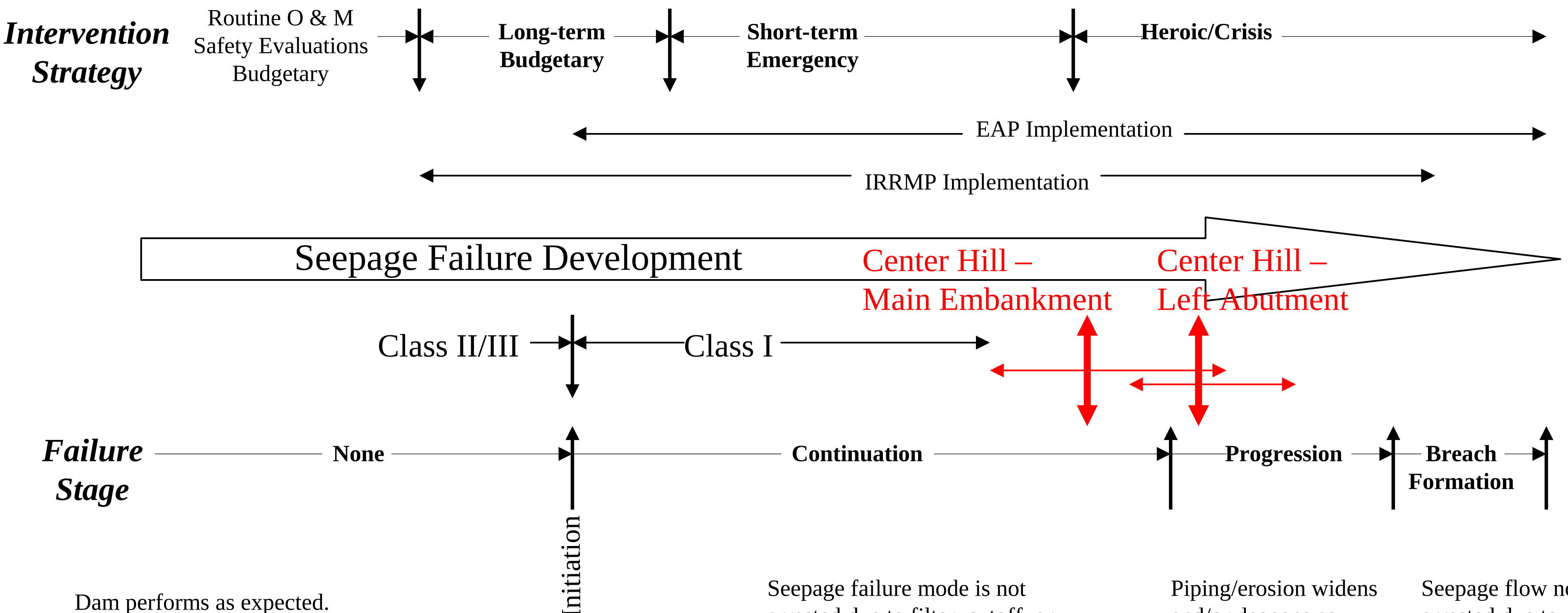
Figure 3

Estimated Condition for Center Hill Main Embankment Dam and Left Abutment

Long-term intervention may include:
- Filters/drains
- Positive cutoffs
- Grouting
- Filter/drainage berms
- Relief wells

Short-term intervention may include:
- Modified operations
- Reservoir drawdown
- Reservoir restrictions
- Grouting
- Filter/drains/berms
- Relief wells

Heroic/Crisis intervention may include:
- Emergency drawdown
- Evacuation of downstream residents
- Filters
- Downstream gradient reduction
- Crack or pipe filling



Dam performs as expected. Routine safety inspections show no problems. Safety evaluations may suggest potential for long-term seepage concern.

Seepage failure mode initiates due to loading event that causes development of concentrated leak or backward erosion. Initiation may occur in the embankment, in the foundation, or at the interface between the embankment and foundation.

Seepage failure mode is not arrested due to filter, cutoff, or other intervention activity. The piping or erosion continues toward the source of water at accelerating rate due to increasing gradients and flow quantity.

Piping/erosion widens and/or deepens as flows increase due to roof formation and no other restraint to growth. Amount of flow continues to increases causing piping/erosion feature to grow rapidly.

Seepage flow not arrested due to collapse and erosion continues until dam crest is breached due to sinkholes, crest settlement, instability of slopes, or unravelling of the downstream slope

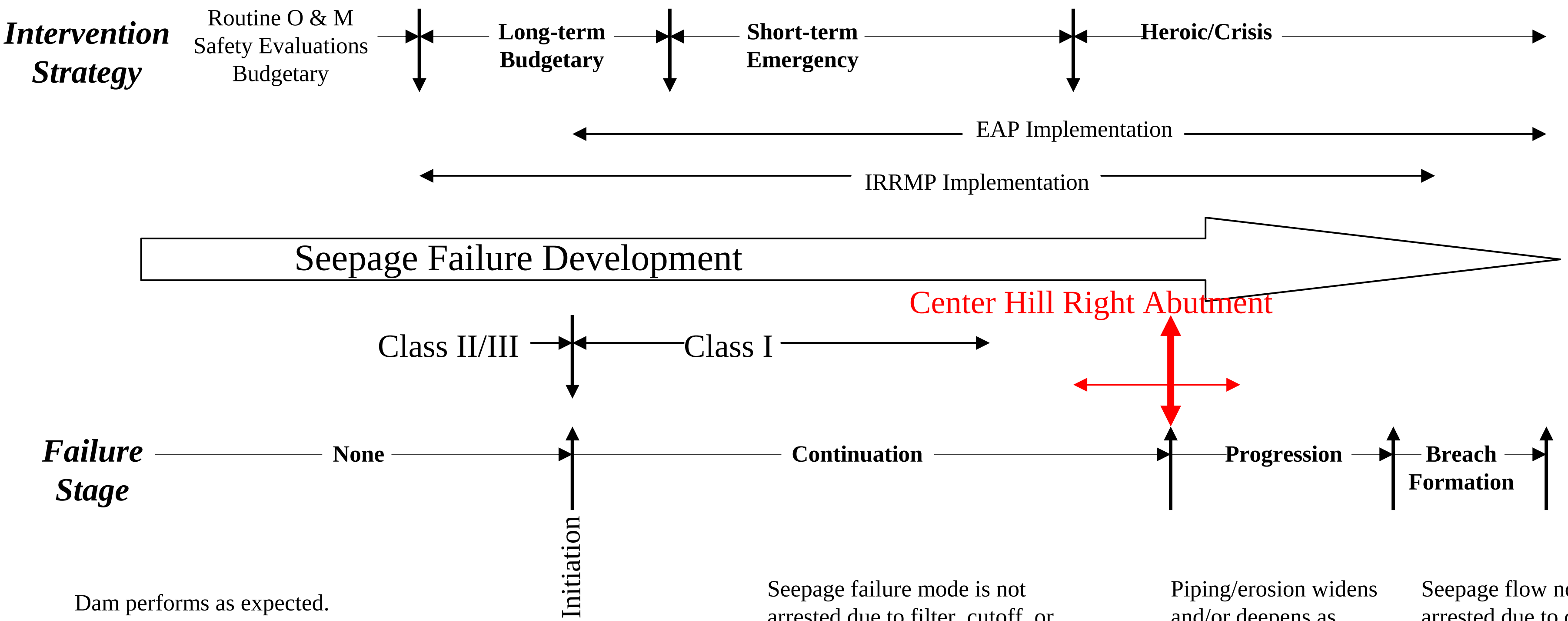
Figure 4

Estimated Condition for Center Hill Dam Right Abutment

Long-term intervention may include:
- Filters/drains
- Positive cutoffs
- Grouting
- Filter/drainage berms
- Relief wells

Short-term intervention may include:
- Modified operations
- Reservoir drawdown
- Reservoir restrictions
- Grouting
- Filter/drains/berms
- Relief wells

Heroic/Crisis intervention may include:
- Emergency drawdown
- Evacuation of downstream residents
- Filters
- Downstream gradient reduction
- Crack or pipe filling



Dam performs as expected. Routine safety inspections show no problems. Safety evaluations may suggest potential for long-term seepage concern.

Seepage failure mode initiates due to loading event that causes development of concentrated leak or backward erosion. Initiation may occur in the embankment, in the foundation, or at the interface between the embankment and foundation.

Seepage failure mode is not arrested due to filter, cutoff, or other intervention activity. The piping or erosion continues toward the source of water at accelerating rate due to increasing gradients and flow quantity.

Piping/erosion widens and/or deepens as flows increase due to roof formation and no other restraint to growth. Amount of flow continues to increases causing piping/erosion feature to grow rapidly.

Seepage flow not arrested due to collapse and erosion continues until dam crest is breached due to sinkholes, crest settlement, instability of slopes, or unravelling of the downstream slope

Prepared by DSAC Peer Review Panel
12-06

5.0 Dissenting Views

Members of the Panel have been contractually provided a framework to express a dissenting view or views in the form of a "Non-concurrence" report. This report represents a "consensus opinion" of the entire Panel. There are no dissenting views by any member of the Panel. Variations in Panel member opinions are represented by the confidence band presented on Figures 3 and 4.

6.0 SPRA and Proposed Risk Reduction/Mitigation Measures

6.1 SPRA Failure Modes

SPRA (Screening Portfolio Risk Assessment) is an internal tool developed by USACE to perform initial risk characterization of the USACE dam inventory, and identify the highest risk projects for risk management decision making.

In support of the SPRA completed by the Corps, the Panel concurs with the potential failure modes that have been identified. The failure modes identified by the SPRA are 1) Embankment Abutment Seepage and Piping, and 2) Embankment Foundation Seepage and Piping. Two additional failure modes have been identified by the Panel as having a potential for concern:

- Saddle Dam Foundation Seepage, Piping and Erodability. The MRE Report describes leaks under the saddle dam that increase substantially during high pool elevations. The failure mode of concern for the saddle dam is similar to the failure mode explained in Section 6.2.1. below for the main embankment dam. Erosion in Karst features of the foundation will undermine the embankment causing sinkholes to develop in the upstream face of the dam that will release the reservoir through the sinkholes causing rapid erosion, collapse of the dam and release of the reservoir. Additional distress indicators of this failure mode are that the existing grout curtain under the saddle dam is over 50 years old and was not adequately installed in accordance with current practices (i.e. 25 percent of holes not grouted to refusal, single row grouting, unstable mixes, etc.). Limited piezometer data indicate the grout curtain is largely ineffective. More instrumentation data are needed to properly evaluate this condition.

- Concrete Gravity Section Foundation Stability, Seepage and Piping. The MRE Report of 2006 explains very large cavities found and large grout takes during grouting programs under the concrete section of the dam. Foundation drains exhibit increasing flows over the life of the project. Eight of the 24 relief wells that discharge in the tailrace area downstream of the powerhouse flow so strongly that surface turbulence is noticeable with 8 to 10 feet of water ponded over the vertical outlets of the wells. It is evident that piping of the filling material in large cavities is increasing with time. This piping will accelerate as the concentrated leaks become larger, eventually causing loss of the reservoir through large tunnels in the foundation under the concrete section of the dam. As internal erosion continues, uplift pressures will likely also increase because the relief well system will not be able to carry the increased flows. With the possibility of further increases in uplift pressure, stability of the concrete section of the dam should be monitored and re-evaluated on a regular basis. The adequacy of the instrumentation system under the no-overflow gravity spillway and powerhouse portions of the concrete dam should be reviewed and additional instrumentation installed if appropriate so that uplift pressures under each Monolith of the dam can be monitored.

6.2 Failure Modes of Primary Concern

The Panel considers the following two failure modes to be of primary concern:

- Embankment – Foundation Seepage and Piping
- Embankment and Concrete Dam – Abutment Seepage and Piping

Additional discussion of each of these failures modes of primary concern is provided in the following subsections.

6.2.1 Embankment – Foundation Seepage and Piping

Seepage and piping or internal erosion of the soil infilling of the Karst features of the foundation was initiated some time ago (likely upon first impoundment). Noticeable increases in seepage occurred between 1960 and 1984 as evidenced by the seepage problems that developed in the 1970’s including wet areas and sinkholes. The most significant observation was the occurrence of a muddy show of water along the riverbank immediately downstream of the main embankment dam that occurred in 1983. Exploratory drilling in the late 1970’s found many cavities and solution channels crossing the core trench. Additional grouting was performed in the 1983-84 time frame and again in 1993. Subsequent to the grouting, no additional muddy flows have been noted. However, wet areas and seepage continue to increase downstream.

There is a line of increasing piezometer levels and an additional nearby line of decreasing piezometer levels in the dam foundation and signs of increasing rate of settlement of the embankment immediately adjacent to Monolith 29 of the concrete dam. All of these observations are cause for concern. One possible scenario is that a “plume” of high pressures develops in the foundation along a Karst feature and moves downstream in the foundation until exit gradients get high enough at the discharge face to cause erosion of the clay to begin (initiation). The line of rising piezometers may be measuring such a condition. After initiation, the erosion then moves back upstream (continuation), at a much quicker rate than the plume or bulge of high pressure developed. If instruments are at the right location, there would be a drop in pressures as the erosion front moves upstream past the instruments. As the erosion process continues, more and more water enters. Whether this scenario is correct or not, it is possible the changing piezometer levels coupled with embankment settlement in the area are indications that severe piping or flow through Karstic cavities is occurring under the embankment.

The fact that piezometer levels and seepage flows are changing indicates considerable piping and internal erosion are continuing, possibly at a fast rate. It is only a matter of time, and perhaps a short time, until the Karst features under the dam are open enough to allow collapse of the foundation soil and embankment materials that will create sinkholes in the dam. Formation of a sinkhole on the upstream face of the embankment dam or in the upstream foundation would signal the end of the continuation stage of piping development and the start of the progression stage that would likely be rapid and catastrophic, causing loss of the pool, and loss of lives and property downstream. This failure mode has been in progression for 40 years or more.

The Panel considers there may be a number of possible locations along the embankment where this failure mode has been progressing. One location of primary concern is the embankment foundation immediately adjacent to (left of) Monolith 29 of the concrete dam. The Panel judges Center Hill Dam to be in a critical condition related to this failure mode. Immediate corrective actions are necessary.

6.2.2 Embankment and Concrete Dam Abutment Seepage and Piping

There are more distress indicators in the abutments on this site than under the embankment or concrete sections of the dam. As such, progression toward failure is judged to be greater in the abutments than under the embankment section or at the saddle dam. This may be less of a concern than piping under the dam because the seepage path is longer and a breakthrough of the reservoir into an abutment cavity will not collapse the dam and not likely result in as rapid release of the reservoir.

The chain of active sinkholes on the left abutment coupled with the development of large springs and leaks downstream with turbid flow is especially alarming. Several grouting programs have been carried out that have decreased the flows for a time. This mitigation has been short lived as the seepage flows have reestablished and are presently increasing. Prior to grouting in 1993, the Picnic Spring flow often exceeded the 16 cfs weir capacity. After completion of the grouting program, normal flows were reduced to 3 cfs. Flows out of the Quarry Springs and Picnic Spring downstream of the left abutment have increased to approximately 20 cfs since the grouting in the left abutment was completed in 1993. The Panel judges that there is a moderate to high likelihood that “continuation” of the piping failure mode has developed by erosion of soil filling in the large solution cavities in the bedrock of both abutments of the dam. This failure mode has likely progressed to the point where there is a continuous open pathway in the abutment bedrock from the downstream springs to the reservoir and the failure mode in the abutments may be well into a progression stage toward failure.

The Panel judges this failure mode to be in a critically near failure condition as defined in EC 1110-2-6064 (2007), requiring immediate corrective actions as discussed below.

6.3 Proposed Risk Reduction Measures

The Panel has evaluated the proposed risk reduction measures by sorting them into three general categories; 1) immediate, 2) short-term, and 3) long-term.

6.3.1 Immediate Risk Reduction Measures

The Corps has implemented a modified reservoir operations plan (beginning in March 2005) where the pool is maintained near elevation 630 from October to February each year and about elevation 647 between May 15 and July 1 each year. A band width has been established for the operation of the reservoir (named the SEPA Band). The Corps is currently trying to stay near the lower boundary of this band.

The Panel finds that with the modified reservoir operations plan, the current distress indicators signify a risk of failure of the embankment dam or the saddle dam, and/or release of the reservoir through erosion features in one of the abutments or under the concrete dam. Immediate drawdown of the reservoir is recommended to reduce these risks. The proper drawdown level for the reservoir cannot be determined at this time based on available instrumentation data, geological information, and a current understanding of potential consequences associated with lowered pool conditions.

Based on descriptions of distress indicators presented to the Panel during briefings and in the MRE Report, the Panel has considered that Center Hill Dam and all its components is located on and adjacent to Karst terrain. This terrain consists of a system of solution cavities partially filled with soil that began deteriorating as soon as seepage gradients were increased by filling the reservoir. The Panel considers that all portions of the Karst terrain are deteriorating as evidenced by the increasing seepage (some rather dramatic), appearance of wet areas downstream, development of sinkholes, muddy flows, and changing piezometer readings. The Panel further considers that reservoir restrictions is a prudent way to reduce the pressure on the dam and foundation, reduce the rate of piping in the solution cavities, and reduce the volume of the reservoir that would be released if failure were to occur.

To reduce the risks, the Panel recommends the reservoir be lowered as low as possible while still operating and providing most of the reservoir benefits. During the Panel site visit on February 8, 2007 the reservoir level was at elevation 624. With the reservoir at or near elevation 624, apparently for most of the winter months, it is demonstrated that the project could be operated at these lower levels with a portion of the recreational boating facilities affected. The Panel noted that the wet areas downstream of the main embankment dam were nearly dry, the large springs on the downstream side of both abutments were flowing much less than previously with higher reservoir levels, and the leaks downstream of the saddle dam were less. Based on the improved conditions observed during the site visit and the Panel's recommendation that the reservoir be operated as low as possible, the Panel is recommending the reservoir level be lowered to and maintained at or below Elevation 620 to 630 throughout the year until further information is available to evaluate the appropriate reservoir restrictions. This reservoir level should be maintained in the lower portion of this range for as much of the year as possible to minimize hydraulic loading on the foundation and abutments. Hydrologic and dam breach flood routing evaluations should be completed to define downstream risks for storage levels in this range, and to evaluate the ability to maintain the reservoir in this range and minimize the time when reservoir level may exceed elevation 630, particularly when storage levels are above elevation 625 prior to a flood event.

There is a concern that even at reservoir levels below elevation 620 to 630, a large volume of water could still be flowing unobserved through open, subsurface solution cavities beneath the downstream area. These flows could be returning unobserved to the stream at some location downstream and, if observed, would indicate continued progression of the failure modes of primary concern. Such progression could include erosion of material at the base of the embankment dam that may cause sinkholes in the dam and would indicate pool levels lower than 620 to 630 should be recommended. It is imperative that the investigation program proceed as rapidly as possible and that additional instrumentation is installed and monitored to enable better evaluation of the conditions so that the appropriate reservoir restriction can be determined.

The Panel recognizes that there are many important considerations related to establishing a target reservoir restriction level including; 1) potential impacts of dam failure at the drawdown level, and 2) the loss of flood control, water supply, hydropower, and recreational benefits. If the Corps decides to use reservoir restrictions higher than recommended based on these other impacts, the Panel recommends the grouting program begin immediately and proceed as fast as possible to reduce the risks.

The Panel recognizes that the Corps has conducted flood routings of one breach assumption for both abutments, the main embankment dam, and the saddle dam. The Panel recommends that additional flood routings be completed that consider 1) a range of possible failure breach widths and development times, 2) alternative reservoir restriction levels, and 3) without an upstream flood in order to further support the decision regarding the reservoir restriction level to be implemented.

6.3.2 Short-term Risk Reduction Measures

The Panel concurs with the proposed short-term risk reduction program of foundation grouting beginning with the embankment section of the dam and extending into the left and right abutments or if possible, at all three areas simultaneously. The Panel cannot over-emphasize the urgency of this action in concert with identifying, and then maintaining a restricted reservoir level.

Grouting should start immediately. The grouting should be done with Balanced Stable Grout (BSG) where appropriate. In particularly open/high flow regimes, Limited Mobility Grout (LMG) and/or hot bitumen may be need. Grouting should be performed using the most up-to-date techniques to fill voids that have developed since the previous grouting work and to fill the gaps in the current grout curtain. Special grouting measures will be required in the “gap” of the previous grout curtain on the left abutment as detailed by the 2004 Peer Review Panel. Information should be collected during drilling operations for the grouting that will allow further evaluation of the foundation conditions and provide information for design of the new deep wall proposed for long-term risk reduction.

The best available grouting procedures should be used, and the successful contractor should be selected using best value, not lowest bid especially for the “high flow” zones. Very specialized design and construction expertise will be necessary. Further, the proposed grouting program should be independently reviewed by grouting specialists with a proven track record in such conditions. An independent review should address the following:

- Grout hole orientation and patterns (given the clay-filled vertical features in the rock).
- Need for "blow out" preventers in the gallery, while conducting drilling below reservoir levels.
- Definition of the rheological properties of the "stable grouts" (LMG and other materials which will be required .
- Developing procedures for effective grouting in fast flowing water conditions.
- Use a robust (reliable and durable) system to collect and report results of all drilling, water pressure testing and grouting data on a regular and timely basis. Report any unusual events as soon as they arise.
- Water pressure testing requirements (single and multipressure).
- Consideration of refusal criteria for the grouting of each stage.
- Definition of target residual permeabilities .
- Need for complete grouting and drilling logs to verify detailed conditions.

The Panel notes that piezometer installation has already been initiated, and further recommends that the system of instrumentation (piezometers and settlement monuments) and the approach to monitoring should be critically and independently reviewed and altered as appropriate as soon as possible. Appropriate additional investigations and instrument installation should be performed prior to grouting so that a baseline of data is established and the effectiveness of the grouting program can be evaluated.

6.3.3 Long-term Risk Reduction Measures

6.3.3.1 Alternatives Analysis

The Panel has reviewed the Alternative Development provided in the Center Hill Dam – Seepage Control Major Rehabilitation Evaluation Final Report (Briefing Document, dated July 2006). The report describes the alternatives considered in the Major Rehabilitation study for resolving the issues and/or treating the foundation and abutment problems at the dam. Some alternatives stand by themselves, whereas others would have to be performed in combination to resolve the seepage problems at certain reaches or locations within the project. In each case, the alternatives were accepted in whole or part, or eliminated with reasons stated for the elimination.

One alternative studied was to replace the present dam with an RCC dam. The RCC dam alternative was eliminated with a long list of reasons dealing with loss of benefits during construction, cost, risks to life and property, and others. The alternatives were finally consolidated into two arrays of the various alternatives considered for the various reaches or locations within the project. One of these arrays was selected as the "Recommended Plan – Alternative 1."

The Panel recommends that the alternatives analysis be revisited to look at or evaluate the following:

- Consideration of long-term risk (over at least a 50 year period) by incorporating all or pertinent elements of a detailed risk analysis.
- Selection of the preferred alternative based on "best value," also over a period of not less than 25 years, instead of present day least cost values.
- Incorporate the Corps' 3 R's (Robust, Resilient, and Redundant) in the evaluation process and the selection of the preferred alternative.
- Consideration of the Panel's comments on the cutoff wall provided in Section 6.3.3.2 below.

6.3.3.2 Composite Cutoff Wall Alternatives and Abutment Grouting

The Panel believes that a composite cutoff wall (i.e. grouting, plus a concrete cutoff) is a viable long-term risk reduction alternative for the embankment sections of the dam. However, the cutoff wall is not a permanent solution unless the wall reaches sound rock conditions. The extensive grouting and cavity and sinkhole filling explained under Short-Term Risk Reduction Measures above may serve as the long-term measures for the abutments, if appropriately designed and constructed. However, there may be Karst features that are filled with soil that can later erode such that grouting will once again be needed. The following comments are offered for consideration in the Alternative Analysis for those components of the overall array of rehabilitation options that would involve the concrete diaphragm walls:

- The concrete diaphragm wall proposed to be installed from the crest of the embankment and saddle dam sections could be considered a single line-of-defense. The grout curtain near the same location and below the wall may be considered a second line of defense; however, additional grouting may be necessary in the future if soil filled cavities still exist below the wall. The Panel recognizes that options for creating embankments with robust, resistant and redundant (i.e. multiple lines-of-defense) characteristics are limited, potentially very expensive, and could cause significant short-term impacts to important project uses and benefits. When the wall is installed from the crest in combination with the grout curtain installation below the wall, it should be recognized that further treatment/rehabilitation may be necessary in the future since it may not be possible to install a wall to the depth necessary to reach sound foundation conditions. As discussed further below, the Panel encourages the Corps to evaluate other alternatives for modifying the existing embankment dam section and abutments that would provide a solution with multiple lines-of-defense such as all or partial removal and replacement of the embankment to enable wall installation from the foundation surface and foundation treatments that isolate the embankment from Karst features in the foundation bedrock.

- Required depth of wall and related feasibility of construction are major issues to be resolved. The design objective for the depth of the wall and grouting below the wall must be fully addressed. There must be a high degree of confidence that the rock below the toe of the wall has an acceptably low, uniform permeability either naturally or as a consequence of a well-conducted grouting program. The feasibility of wall construction techniques should be evaluated when the additional information from the grouting program is available.
- A full-scale test section should be conducted to confirm constructability and evaluate the performance of a new wall at this site.
- Special attention must be paid during construction to the hydrogeological response of the entire dam/foundation system. The wall will be built with some sort of progressive “closure” system such as primary and secondary panels or piles. The early panels or piles may redirect and focus foundation flow in the Karst and trigger erosion in areas of concentrated flow that threaten the construction work or the safety of the dam. Further pool restrictions may be needed during construction of the wall.
- The integrity of the wall must be proved by appropriate verification methods following construction such as coring and testing of the wall. Localized remediation should be conducted as appropriate.
- Damage to the existing dam needs to be further evaluated. The condition and performance of the embankment are vital to the long-term safety, reliability, and effectiveness of a cutoff wall system. The Corps should assess the condition of the embankment and verify that potential settlement or instability will not threaten the performance of a new cutoff wall system. Damaged portions of the embankment and embankment foundation may require remediation to provide the required support and long-term performance of the cutoff wall system.
- A carefully designed and implemented instrumentation monitoring program will be required to confirm the safe long-term performance of the dam.
- An appropriate positive cutoff wall should be considered under the concrete dam section, again depending on an evaluation of the drilling and grouting work

currently contemplated in this area. The Panel notes a cutoff under the concrete dam would be very difficult, but could call on the successful experience of cutoff construction at W.F. George Dam in Alabama.

The Panel generally agrees with other proposed long-term measures presented in the SPRA briefing on October 9, 2006, including:

- Performing a geotechnical investigation of the Saddle Dam to determine if a cutoff wall or other treatment is appropriate.
- A new seismic evaluation should be performed for the project, since the previous one dates from 1981.

The Panel recommends the Corps establish a suitably qualified “Panel of Experts” to review and provide input to the engineering and construction grouting work. We understand this is currently planned for Center Hill Dam.

6.4 Risk-based Reservoir Pool/Operation Restrictions

6.4.1 Are the proposed risk-based reservoir pool/operation restrictions appropriate?

The Panel understands that some reservoir restrictions were implemented in March 2005 defined by a band that shows the maximum pool elevation at 632 in the winter and 648 in the summer with gradual filling and drawdown between summer and winter. The minimum pool elevations for the band are approximately 626 in the winter and 646 in the summer. The District operators report that they have a goal of keeping the pool at the lower bound of the band. The pool elevation was at 624 during the Panel site visit in February 2007. Seepage quantities and distress indicators were much less at that time than described when the reservoir levels were higher. However, the Picnic Spring was still flowing about 3 to 5 cfs with some evidence of turbidity in the water and the relief wells in the power plant tailrace were still flowing strong enough to cause boils at the surface some 10-feet above the outlets. Based on these observations, the Panel recommends a risk analysis be performed considering limiting the pool level below elevation 620 to 630 at all times until appropriate reservoir restrictions can be evaluated based on existing conditions determined from investigative and monitoring information. The District informed the Panel that the Corps has already engaged a firm to perform risk analyses on Center Hill Dam.

The Panel is uncertain if the recommended pool restrictions can be maintained using existing release controls at the dam, or whether further capacity is needed. This should be studied and if needed, the Corps should evaluate alternative means to increase drawdown capacity and maintain reservoir drawdown should an acute emergency arise. Alternatives that could be considered to increase the drawdown capacity would include additional outlets, or lowering the overflow spillway crest in two of the tainter gate bays. For the later option, the existing gates should be removed and not replaced until long-term seepage deficiencies are corrected.

6.4.2 Are there considerations related to the reservoir pool/operation restrictions that the Panel would like to comment on further?

See paragraph 6.3.1 above.

The current EAP should be reviewed and updated as appropriate and the downstream public should be appropriately informed about the plan. Table-top exercises should be performed to make sure that local emergency action personnel are fully trained on the elements of the plan and its implementation should it become necessary to implement additional emergency actions.

6.5 Time for Response

6.5.1 Service Life Without Intervening Actions

The Panel concludes there are clear signs that each of the major components of this dam is under severe threat and that the foundation conditions are rapidly deteriorating. In particular, the effects of seepage under the embankment dam are clearly causing significant progressive piezometric changes. The piezometer readings are increasing along one line under the embankment and decreasing along another line, which indicates significant changes in the seepage pattern is occurring. These changes are not fully understood at this time, but it is likely that piping is occurring under the main embankment section.

Seepage flow through the Left Rim gap has created sinkholes and blowouts of major proportions already. The dam has been in service since 1952, and it took about 18 years for sinkholes to appear. Without immediate intervention, further development of these open features will continue at an accelerating rate.

Without any intervention, it is the Panel’s opinion that there is a very high likelihood of breach formation and loss of reservoir through the embankment section and its foundation or through the abutments, and that this could occur at any time. This may be less than the time that will be required to complete the planning, design and construction of short- and long-term corrective actions. This justifies the need to maintain a low pool level while studies for short- and long-term corrective actions are being made.

6.5.2 Recommended Timeframe to Implement Actions

The Panel agrees with the start of an intensive grouting program along the alignment of the proposed concrete cutoff wall and in the abutment rims. The systematic grouting in the foundation will have many benefits including:

- Exploration of the rock in the foundation
- Repair of the rock to permit a diaphragm wall to be constructed safely
- Treatment of the rock in regions where minimal clay infill is present

The grouting in the abutments will involve highly specialized means, methods, and materials and will improve the seepage conditions and reduce the potential for sinkhole development and loss of the reservoir through the many large solution cavities.

The Panel recommends the following actions be implemented as soon as possible:

- Maintain reservoir restrictions below elevation 620 to 630
- Begin foundation and abutment grouting program as soon as possible
- Update the flood routing and consequences evaluation
- Review the instrumentation program, install appropriate instruments, and implement updated monitoring program
- Perform a formal risk analysis
- Review reservoir restrictions based on information from the above items
- Reevaluate the alternatives considering the short and long-term risks and consequences of the possible risk reduction measures
- Design and construction of selected alternative

6.6 Distress Indicators or Triggering Events

The Corps has identified numerous significant distress indicators or triggering events associated with the failure modes of primary concern. These include:

- Numerous active sinkholes in left abutment (both upstream and downstream of the dam)
- Known geology (solution voids) under the embankment with the same conditions as the left abutment
- Open solution caverns in the right abutment
- Large soil discharges from solution caverns
- Significant increase in downstream seepage
- Development of downstream wet area
- Settlement of the main embankment dam crest
- Changes in piezometric pressures in the foundation of the embankment including a line of increasing piezometric levels and an additional line of decreasing piezometric levels
- Mapped depressions on the upstream embankment toe

Additional indicators that would trigger some emergency action include:

- Additional and accelerating settlement of the embankment dam, downstream slope, or slope movement indicating shear failure
- Whirlpools in the reservoir indicating concentrated leakage

We assume that these indicators will continue to be observed to a greater intensity until risk reduction measures are implemented. The Corps should determine what changes in the distress indicators would warrant implementation of the project Emergency Action Plan (EAP), perform at minimum a functional exercise test of the EAP, and update the EAP as may be appropriate based on the results of the functional exercise.

6.7 Questions asked of the Panel

The Corps of Engineers provided the following questions to be responded to by the Panel.

6.7.1 Is the proposed remediation with a cutoff wall appropriate?

The Panel believes that any form of cut-off installation will be beneficial. However, there are significant design, dam safety, constructability, and schedule issues and concerns related to the proposed composite cutoff wall system as discussed in Section 6.3.3.2. above.

The Panel further notes that the short-term grouting program that must be underway shortly will provide the information related to the foundation conditions for completion of the final design of the wall. The Panel encourages the Corps to take maximum advantage of this opportunity and to make information from the expedited grouting program available at the earliest possible time for peer review.

6.7.2 Residual risk in final product due to existing embankment and foundation damage?

The Panel believes there are potential risks associated with the deep cutoff wall construction and there is a potential for this method to cause severe short-term damage to the system during construction. The Panel believes that if the wall can be safely constructed, it will likely provide significant reduction in seepage pressures and quantities in the dam and dam foundation downstream of the wall. Existing seepage/piping pathways within the area of the wall would consequently be disrupted. This will substantially reduce the potential for a foundation piping feature to continue toward the upstream reservoir, or allow the progression of a piping feature leading to the potential for breach formation.

However, if the wall is not deep enough, or the grouting below the wall does not cutoff the significant Karst defects in the limestone formations below the base of the cutoff wall, it will only be a matter of time before a similar seepage concern and potential failure mode develops under this wall. The design life of the proposed wall is; therefore, unknown and should be considered in the alternative analysis. The gradient under the wall will be increased substantially when the reservoir level is raised after it is installed. If any piping prone materials or conditions exist under the wall, it may be only a short time until more remediation will be necessary. In this case, the benefit of the wall may be to extend the time for remediation until new techniques are developed for treating Karst foundation conditions.

6.7.3 Reliability of cutoff wall?

The Panel does not believe there is sufficient information at this time to develop an estimate of the annualized probability of failure (reliability) for the proposed risk reduction alternative. Any estimate will likely have a very significant margin of uncertainty. Additional information obtained during the expedited grouting program may assist with the development of such a refined estimate. The Panel does however offer the following comments with regard to reliability:

- In general, the reliability will be improved by installing the composite cutoff wall to a sound foundation layer or to the greatest depth possible.
- If it were practical, the desired reliability may be obtained by replacing the existing embankment section with a new RCC dam or in the case of the main embankment dam, with removal and replacement of the downstream portion of the dam. The removal of the dam or a section of the downstream slope allows treatment of the Karst foundation as described in previous sections. A deep concrete wall can then be constructed from the foundation level which allows for deeper wall construction than constructing the wall through the existing embankment.

6.7.4 Is an embankment dam ever appropriate in this environment?

The Panel believes that an embankment dam is not appropriate for the Karst environment found at Center Hill Dam unless extensive methods are employed to prevent the erosion of embankment materials and the formation of sinkholes in the embankment dam. These treatments include:

- Removing alluvium under the entire dam and exposing the rock surface
- Placing a substantial concrete slab on the top of the rock under the entire dam capable of spanning solution cavities under the dam (the dam is separated from the Karst foundation).
- Grouting prior to construction of the cutoff wall to treat the Karst foundation to the depth needed for a cutoff wall and beyond to treat the foundation under the cutoff wall and in the abutments beyond where the cutoff wall will end.
- A concrete cutoff wall is placed through the solution cavities in the foundation down to a low permeability stratum if possible or to where grouting has reduced the permeability of the foundation rock.

6.7.5 Feasibility of replacing/reinforcing embankment with an RCC dam?

On the surface, this proposal appears to be impractical, from the standpoint of cost and the time to remove the old dam, treat the foundation, and build a new dam, with loss of all benefits during this period. The Corps has studied this alternative in the alternatives analysis and eliminated it on the basis of at least 10 reasons, the most compelling being that the economic consequences to the surrounding communities would be devastating.

The Panel recommends that the previous alternatives analysis be revisited and that alternatives be developed and evaluated that would weigh the options that allow a cutoff wall to be installed from the foundation level and constructing RCC or a replacement embankment to include other non-erosive features for the dam constructed on the Karst foundation. This analysis should be performed by an independent party (internal or external). This analysis should include relocating the dam upstream or downstream from the present site, or other viable options. The new alternatives analysis should be done to evaluate the benefits of performing these risk reduction measures now rather than in the future when costs will be much higher. The negative economic consequences of having to undertake significant risk reduction measures in the future will be far greater than what they are today.

6.7.6 What are the Possible Failure Modes in the Right Abutment?

The Panel believes the most likely failure mode in the right abutment is for continued piping in the solution channels of the Karst features such that a major breakthrough occurs between one of the downstream caves and the reservoir. This will empty the reservoir down to the level of the solution channel. The resulting flood downstream may or may not be sufficient to cause severe flooding sufficient to endanger life and cause severe property damage. In addition, a sliding failure of the dam as a result of movement of a foundation block beneath the right abutment may also be a failure mode to consider.

6.7.7 Will Cutting Off Seepage Make the Abutment More Unstable?

Generally, cutting off the seepage should make the abutment more stable since the hydrostatic pressure downstream of the cutoff in the abutment would be less. If previous stability analyses have been made, the Panel suggests they be performed again using appropriate seepage pressures with a cutoff wall in place.

The Panel notes that the seepage pathways through the right abutment are much shorter than the pathways in the left abutment. When an effective grout curtain is installed in the right abutment, large heads (near reservoir level) will exist on the upstream side of the grout curtain. With the shorter seepage pathways, the gradients will be greater for the right abutment. Consequently, any cutoff should be capable of withstanding the high heads and gradients in order to provide a long term solution. In considering alternatives, a concrete wall may be a more long term solution for the right abutment.

7.0 Conclusions and Recommendations

The U.S. Army Corps of Engineers (Corps) DSAC (Dam Safety Action Classification) External Peer Review Panel (Panel) has found that the Corps Class I designation (Urgent and Compelling) for Center Hill Dam under EC 1110-2-6064 "INTERIM RISK REDUCTION MEASURES FOR DAM SAFETY" dated May 31, 2007 is appropriate. There is compelling evidence that a piping failure mode has initiated (perhaps in several locations in the left and right abutments, and under the main and saddle embankment dams) and is in an advanced "continuation" stage of development.

The Panel believes that components of the Center Hill Dam are very far along the continuum of failure under normal operating conditions. The fact that a massive blow out has already occurred downstream, and that sinkholes, wet patches and other piezometric indicators of a deteriorating Karstic system have been recorded, justify the very high level of concern held by all parties relating to the risks posed by this dam. It should also be noted that no concrete cutoff has been installed so far and that all foundation remediation has been by grouting using traditional methods at the time of installation including unstable mixes and in some cases without refusal. These grouting methods would not meet today's standards for grouting. Therefore, the seepage cutoff is considered unreliable and unable to prevent progression of piping and internal erosion toward failure. The time at which such a failure would occur is very difficult to predict and it is important to take immediate action to reduce risks to the public.

The Panel's recommendations are as follows:

1. **Immediate Action – Maintain a Lower Reservoir Level:** The Panel notes that the Corps has performed evaluations regarding the seepage concerns at Center Hill dam and continues to evaluate safety related issues regarding the dam's performance. As a result of these evaluations, the Nashville District and Headquarters, the Corps has implemented a modified pool operation plan that generally targets pool levels below elevation 630 in the winter and below elevation 648 in the summer.

   The Panel recommends immediate action to maintain the reservoir level as low as possible while still operating and providing most of the reservoir benefits. During the Panel site visit on February 8, 2007, the reservoir level was at elevation 624. With the reservoir at or near elevation 624 for most of the winter months, it is demonstrated that the project can be operated at these lower levels with a portion of the boating facilities affected. The Panel noted that the observable distress indicators were much improved from descriptions and photographs of distress indicators at higher reservoir levels. Based on the improved conditions observed during the site visit and the desire that the reservoir be operated in the range of elevation 620 to 630, which is in line with the winter levels of the current pool operations plan, the Panel recommends maintaining the pool level at or below elevation 620 to 630 all year. This pool restriction should remain in place until further information is available from field investigations and the grouting program to enable a better evaluation of the appropriate reservoir restrictions – be it higher or lower.

The proper drawdown level cannot be determined at this time based on available information regarding the foundation conditions, and a current understanding of potential consequences associated with lowered pool conditions. The Panel recommends that investigations and grouting proceed as soon as possible to provide the needed information to determine the appropriate reservoir restrictions.

The Panel finds that current distress indicators signify a risk of failure, with normal pool operation, of the embankment dam, or the saddle dam, and/or release of the reservoir through erosion features in one of the abutments or under the concrete dam. The Panel considers pool restrictions essential to reduce these risks, but recognizes that the Corps may decide on other action based on judgments regarding consequences of using lower pool levels unknown to the Panel.

Coupled with operating at a lower pool level, the Panel recommends a review of the emergency action plan and updating it if needed. Emergency response entities should be notified to be on an enhanced state of preparedness to follow the emergency action plan. Surveillance of the dam and the distress indicators should be maintained at a high level.

2. **Short-term Remedial Actions to be Started as Soon as Possible:** To reduce the risks of failure of the structure and to establish an appropriate restricted reservoir level, the Panel recommends the following short-term actions:

    a. **Begin Foundation and Abutment Grouting Program as Soon as Possible:** The planned grouting program for the main embankment dam, saddle dam, left abutment, and right abutment rim should be completed as soon as possible. The grouting should be accomplished using the most up-to-date methods to make sure the grout curtain is effective and that important information of foundation conditions is collected for evaluating the reservoir restriction level and for design of the proposed cutoff wall or other remediation measures. The grouting contractor should be procured by "Best Value" as opposed to "Low Bid." We expect that the bidding documents will address, in particular:

        - Grout hole orientation and patterns (given the clay-filled vertical features in the rock)
        - Need for "blow out" preventers, while commencing drilling below reservoir levels

- Definition of the rheological properties of the "stable grouts" LMG and other materials which will be required
- Developing procedures for effective grouting in fast flowing water conditions
- Use a robust (reliable and durable) computer-controlled system to collect and report results of all drilling, water pressure testing and grouting data and reporting results on a regular and timely basis
- Consideration of refusal criteria
- Definition of target residual permeabilities
- Water pressure testing requirements (single and multipressure)
- Need for complete grouting and drilling logs to verify detailed conditions

b. **Update the Flood Routing and Consequences Evaluation:** An update of the flood routing and consequence evaluation should be completed as soon as possible to aid in the evaluation of pool restrictions. The Panel requests the opportunity to review the results of any additional downstream flood routings and consequence evaluations as soon as available in order to finalize recommendations related to pool restrictions.

c. **Improve the Existing Instrumentation, Monitoring and Evaluation Program:** It is noted that additional piezometers are currently being installed. The Panel recommends a comprehensive peer review of the current and proposed instrumentation program be completed as soon as possible so that the current instrumentation system can be modified as needed. The purpose of the instrumentation and evaluation is to determine the condition of the main and saddle dams prior to, during, and following completion of the expedited grouting program.

The Panel recommends installing additional settlement monuments on the crest of the dam to make the spacing between monuments a maximum of 25 feet. Surveys on these closely-spaced monuments will provide better information relating to settlements that may be associated with loss of support under the dam due to erosion of soil from solution cavities.

d. **Perform a Formal Risk Analysis:** A formal risk analysis should be performed considering alternative reservoir restriction levels and downstream consequences to assist with project decision making and evaluation of reservoir drawdown and operations restrictions. The Panel notes that a contract has been awarded to perform a risk analysis on Center Hill Dam.

e. **Review Reservoir Restrictions:** Once completed, the results of the supplemental investigation, instrumentation monitoring, and grouting programs should be reviewed to determine whether the reservoir restrictions are appropriate and to make modifications if needed. Adjustments could be to relax and allow higher water levels, but they may also be to further restrict the pool level to mitigate concerns about critical conditions found.

   f. **Maintain Frequent Observations and Evaluation of Uplift Pressures Under the Concrete Section of the Dam:** The deteriorating seepage conditions under the concrete section of the dam could cause uplift pressures to increase under the T3 bentonitic layer in the foundation. Using previously completed stability analyses, the pressures where unstable conditions are approaching can be determined and measures taken to avoid problems.

3. **Long-term Risk Reduction Measures Evaluation and Design:** The Panel recommends the following process for determining and implementing the appropriate long-term remedial measures:

   a. **Revisit the alternatives analysis:** The Panel recommends that the previous alternatives analysis be revisited and that alternatives be developed and evaluated that would weigh the options that allow a cutoff wall to be installed from the foundation level. These options could be a new RCC dam or partial/full removal/replacement of the existing embankment dams with appropriate foundation preparation and treatment. The cutoff wall installed from the foundation level will have a much longer life than one installed from the embankment crest and a concrete dam will be much more resistant to erosion than the present embankments. The new alternatives analysis should evaluate and compare short and long-term risk reduction measures so that a "risk informed" decision can be made considering the best value over the long-term versus one based on today's least cost and least negative consequences.

   b. Proceed with the design and construction of the alternative selected based on best value.

Attachment A

References

References:

1. US Army Corps of Engineers, EC 1110-2-6064 INTERIM RISK REDUCTION MEASURES FOR DAM SAFETY,May 31, 2007.

2. US Army Corps of Engineers, Center Hill Dam, DeKalb County, Tennessee, Seepage Control, Major Rehabilitation Evaluation Final Report, Nashville District, July 14, 2006.

3. US Army Corps of Engineers, Center Hill Dam, Major Rehabilitation Evaluation Briefing Document, July 2006.

4. US Army Corps of Engineers, Nashville District, Center Hill Dam Peer Review Briefing, Pittsburgh, PA, by Jody Stanton, October 9, 2006.

5. US Army Corps of Engineers, Class I Dam SPRA Summary, Center Hill Dam; Presentation to DSAC Review Panel by Dr. Jeff Schaefer, Pittsburgh, PA, October 9-13, 2006.

6. DSAC External Peer Review Panel, "Draft Comments/Questions related to ETL 1110-2-XXXX, INTERIM RISK REDUCTION MEASURES FOR DAM SAFETY", September 19, 2006, version 1, December 14, 2006.

7. DSAC Class I Dam Peer Review Panel, Confidential Draft Summary Memorandum, Evaluation of DSAC Classifications for Wolf Creek, Center Hill, Clearwater, Isabella, Martis Creek Dams and Herbert Hoover Dikes, December 14, 2006.

Attachment B

Photographs


Lower Leak flow
during site visit
Photo No. 1


Boat Ramp Cave
– not flowing
during site visit
Photo No. 2


Photo No. 3
Picnic Spring flow
Feb. 8, 2007


Picnic Spring flow
– slightly cloudy
Photo No. 4

Photo No. 5

Major Sinkhole on Left Abutment


Sinkhole and Entrance Point on
Upstream Side of Left Abutment
Photo No. 6


Apparent Low Spots on
Crest of Dam
15
Photo No. 7
Top of Embankment at end of
Concrete Section